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Visual Grading Analysis of image quality in pediatric abdominal images acquired by Direct Digital Radiography and Computer Radiography Systems

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Purpose

The advent of digital technology allowed for great improvements in radiology and lead the way for digital radiology, leaving behind conventional x-ray techniques, [1]. Digital post-processing of image is the main advantage of digital image systems (e.g., computed radiology and direct digital radiology) over the conventional systems. Image quality can indeed be improved avoiding the increase of patient dose and the number of unnecessary exposures [1-3].

Image quality is directly linked to the dose of radiation applied to the patient. The literature points out the need for appropriate image evaluation in order to reduce the patient dose. Optimization and practice justification are of great relevance in diagnostic radiology. In pediatric patients a good practice justification is even more important as radiation exposure on the first 10 years of life increases the possibility of negative effects on the patient's health compared to an exposure between the ages of 30 to 40 years old [4, 5].

In the past, the main concern of radiology technicians was image quality, leaving radiation dose to a second plan. Nowadays, dose reduction and the cost/benefit ratio represent the main concerns in radiology. The radiographer is responsible for applying the ALARA (As Low As Reasonable Acceptable) concept in every study involving the use of ionizing radiation [4, 6]. According to the ALARA concept, the necessary level of diagnostic image quality should be attained with the lowest patient dose possible.

In Pediatric radiology, besides the ALARA principle, the International Commission on Radiological Protection (ICRP) adds a new concept - the SMART message, also related with optimization and radiation protection when applied to pediatric radiology (Figure 1) [6].

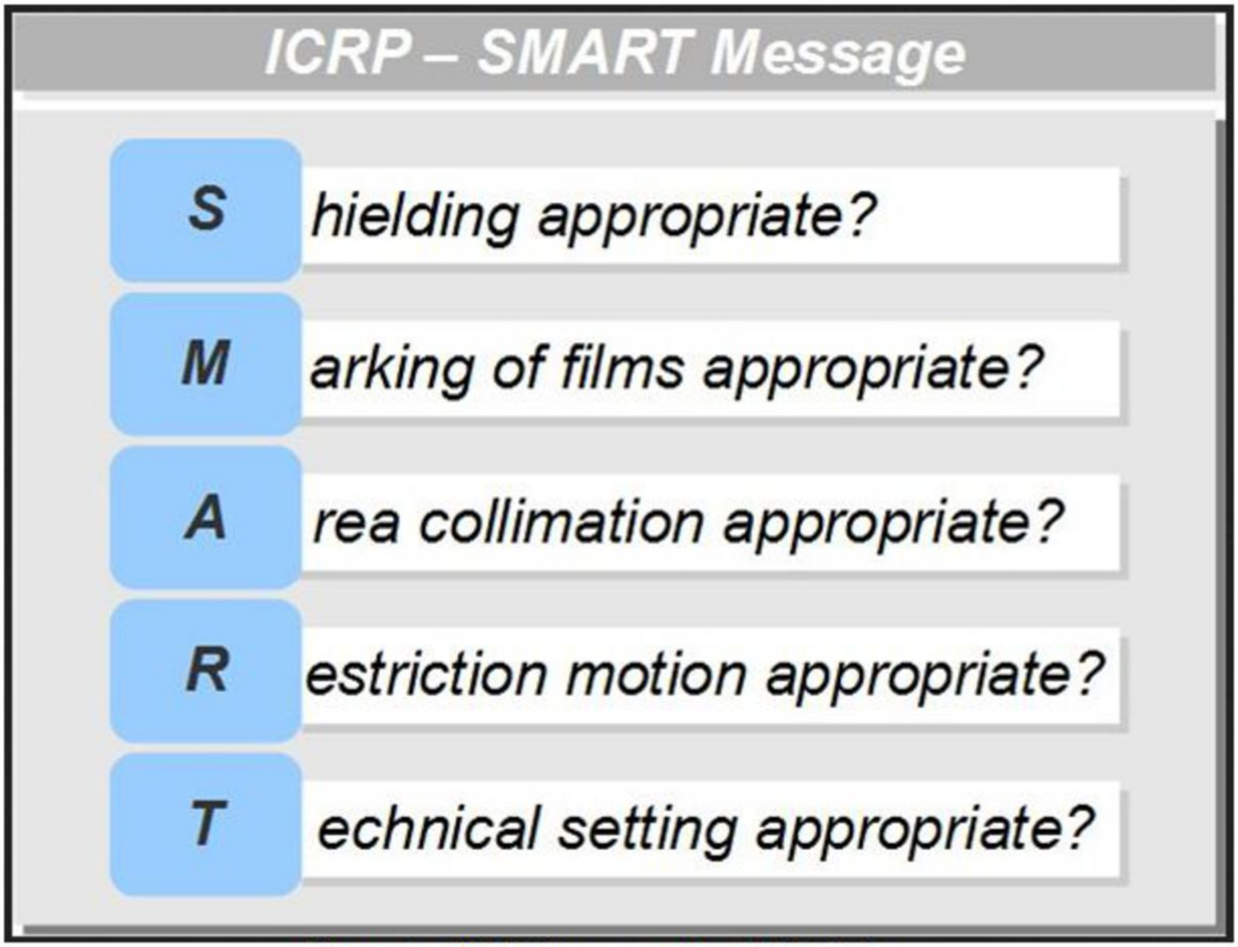

Figure 1 - SMART message from ICRP [6]

Fig. 1
References: Figure adapted from: Alexakhin RM, Menzel H. The 2007 Recommendations of the International Commission on Radiological Protection, 2007.

There are several methods to evaluate image quality: objective (phantom based) or subjective. In the subjective methods, the evaluation is based on the observer's perception guided by some kind of image quality criteria that must be accomplished. The European Commission published a set of Guidelines on Quality Criteria in order to suggest standard protocols for a broad range of radiographic procedures responding to the diagnostic needs with acceptable dose, and establish image quality criteria that should be accomplished in the evaluation of the obtained images.

In this context, the main goal of the present study is to evaluate and compare the quality of radiographic abdominal pediatric images, acquired by direct digital radiography (DR) and computed radiography (CR) systems.

Image quality evaluation was performed through a subjective method known as Visual Grading Analysis (VGA) [5].

Images for this section:

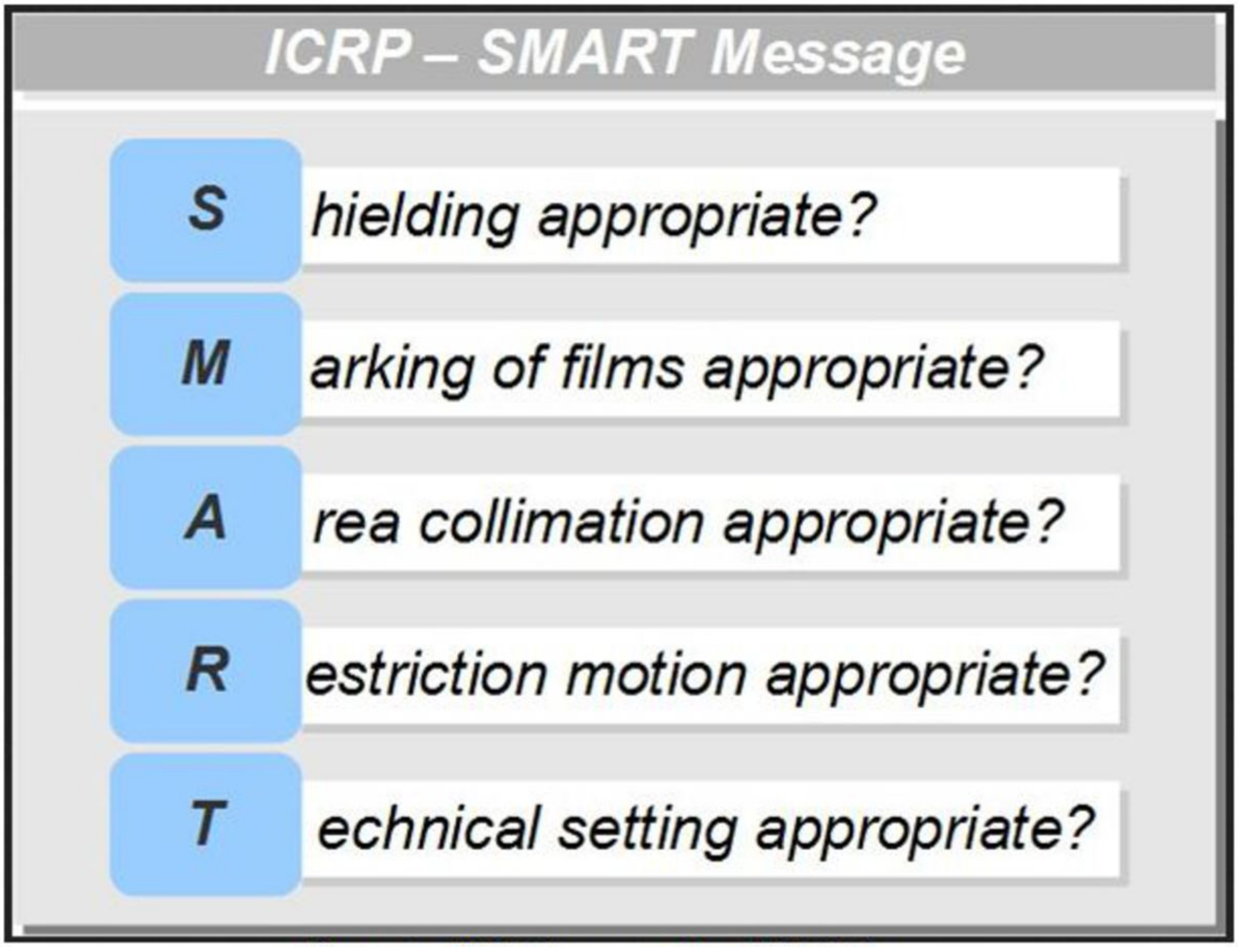

Figure 1 - SMART message from ICRP [6]

Fig. 1

Methods and Materials

Sample description

In this study, a sample of 44 images of pediatric abdomen was used, from children aged between 5 to 10 years. The data was collected in two institutions, referred as Institution A and B. Institution A was equipped with a DR system and Institution B with a CR system. Imaging protocols were slightly different with respect to exposure factors (Table 1).

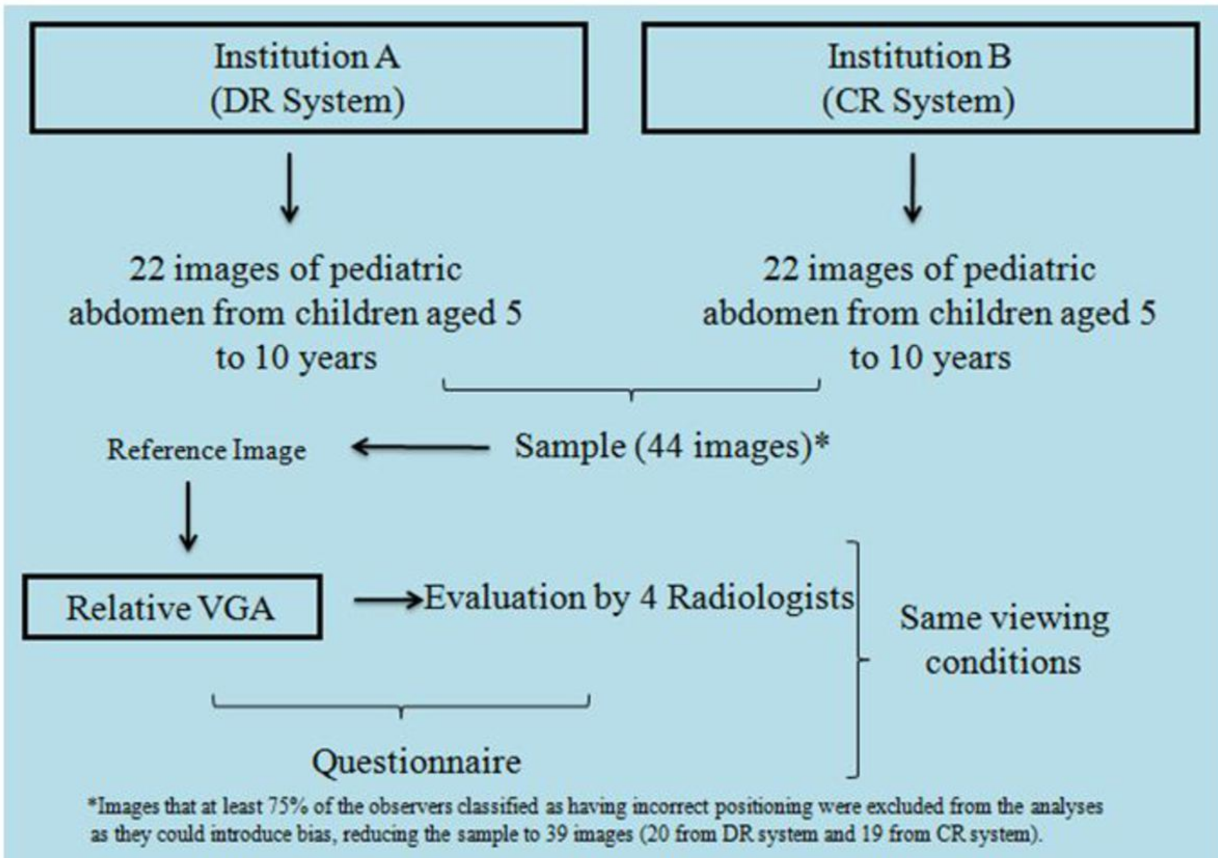

Figure 2 – Schematic view of the study

Fig. 2
References: - Aveiro/PT

Protocols	Parameters	European Guidelines (Conventional Radiography)	Institution A Protocol (DR System)	Institution B Protocol (CR System)
	Patient Position	Supine or prone	Orthostatism.	Supine or orthostatism
	Radiographic device	Table, grid table	Grid table.	Table, grid table
	Nominal focal spot value	0,6 (≤ 1,3)	Thick	Thick
	Additional filtration	Up to 1 mm Al + 0,1 or 0,2 mm Cu (or equivalent)	2mm Al	2mm Al
	Anti-scatter grid	No grid for infants < 6 months of age	Grid	• Supine: no grid • Orthostatism: grid
	FFD	100 - 115 cm	100 cm	100 cm
	kV	65 - 85	70	67
	mAs	-	12,5	20
	Automatic exposure control	Chamber selected - central or both lateral	Chamber selected - central or both lateral	Chamber selected - central
	Protective shielding	Gonad capsules for male patients. Lead-rubber coverage of the thorax in the immediate proximity of the beam edge.	-	-

Table 1 - Protocols used in institutions participating in the study

Table 1
References: - Aveiro/PT
Image quality evaluation

Image quality evaluation was performed through a subjective method known as VGA. This method can be used to assess, in a scientific way, whether or not the images comply with the established criteria [4, 7]. The criteria used in this study is in line with the one established in the European Guidelines on Quality Criteria for Diagnostic Radiographic Images in Paediatrics (EGQCDRIP), a document based on the work carried out by several renowned entities and different professionals. For more details please refer to [4].

The VGA method has two variants: the absolute, where the scores are given on an absolute scale, and the relative, where the image quality ought to be compared with a reference image. In the relative VGA, usually a five level scale (ranging from "much worse" to "much better") is used to assess whether or not the image is better than the reference image (Table 2) [5, 8, 9]. The VGA score can be calculated using the following equation (appearing as figure 8):

$$VGA_{Score} = \frac{\sum_{i=1}^{I} \sum_{s=1}^{S} \sum_{o=1}^{O} G_{i,s,o}}{I \times S \times O}$$

Fig. 8
References: Tingberg A. Evaluation Of Image Quality Of Lumbar Spine Images: A Comparison Between FFE And VGA. Radiation protection dosimetry. 2005;144:53-61.

Where $G_{i,s,o}$ is the grading (-2, -1, 0, +1, +2) for image *i*, structure *s* and observer *o*. *I* is the number of images; *S* the number of structures; *O* the number of observers [5, 9].

Evaluation	Viewed Structure
-2	Clearly lower than the reference image
-1	Slightly lower than the reference image
0	Equal to the reference image
1	Slightly better than the reference image
2	Clearly better than the reference image

Table 2 - Classification system used in VGA [5, 10]

Table 2
References: - Aveiro/PT

The images were evaluated by four observers (radiologists), with a professional experience ranging from 5 to 29 years. This assessment was based on a questionnaire grounded on the European Guidelines [4] for this specific examination (Table 3, Figure 3).

AP/PA PEDIATRIC ABDOMINAL PROJECTION WITH VERTICAL/HORIZONTAL BEAM	
Image criteria	• Visualization of the abdomen, from the diaphragm to the ischial tuberosities, including the lateral abdominal walls. • Visualization of the properitoneal fat lines consistent with age. • Visualization of the kidney outlines consistent with age and depending on bowel content. • Visualization of the psoas outline consistent with age and depending on bowel content. • Visually sharp reproduction of the bones.

Table 3 - Image Criteria of AP/PA Pediatric Abdominal Projection [4]

Table 3
References: - Aveiro/PT

Anatomical structures AP/PA Pediatric Abdominal Projection	Image Code																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Visualization of the abdomen, from the diaphragm to the ischial tuberosities																						
Visualization of the lateral abdominal walls																						
Visualization of the properitoneal fat lines																						
Visualization of the kidney outlines																						
Visualization of the psoas outline																						
Visually sharp reproduction of the bones																						
Total Score																						
General aspects (yes or no ansewrs for each image)																						
Proper positioning																						
Proper centering																						
Proper collimation																						

VGA Study

Further sample caracterization

Figure 3 - Questionnaire completed by observers for image evaluation

Fig. 3
References: - Aveiro/PT

Since relative VGA was used in this study, an image fulfilling all the European Guidelines (EG) requirements was selected from the 44 images of the sample and was considered the reference image (Figure 4). The questionnaire was completed in accordance with a five level scale as shown in (Table 2).

Figure 4 - Reference image used in VGA evaluation

Fig. 4
References: - Aveiro/PT

Aiming for a more thorough description of the sample used in this study, besides the specific evaluation criteria for abdominal radiography, considered in the VGA method, a set of three items was added: positioning, centering and collimation. These items were classified as YES / NO by the observers.

All evaluations were performed independently on the same physical space, with reduced luminance and high-resolution display systems. It is noteworthy that the observers were not allowed to manipulate the images (display window) to maintain the original contrast. They were blinded to the detector system used to acquire the images.

The Entrance Surface Dose (ESD) value, for each of the systems where the images were obtained, was estimated using MICADO software (Figure 5).

Figure 5 - MICADO software interface screenshot [Available on: Institut de Radioprotection et de Sûreté Nucléaire (IRSN), website: http://nrd.irsn.fr/index.php?page=micado]

Fig. 5
References: Institut de Radioprotection et de Sûreté Nucléaire (IRSN), website: http://nrd.irsn.fr/index.php?page=micado

Statistical Analysis

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS) version 19.0.

The images which at least 75% of the observers classified as having incorrect positioning were excluded from the analyses as they could introduce bias. Because of this, the sample was reduced to 39 images (20 from DR system and 19 from CR system).

Interclass Correlation Coefficient (ICC) was used to evaluate data reliability through agreement among the four observers. The observers were considered unique and the images represent a random sample.

Student-t test was used to determine differences in the means of the two independent quantitative variables since the assumptions of normality were validated by the Kolmogorov-Smirnov test (KS).

A significance level of 0,05 (# = 0,05) was considered for all the tests performed. The final classification of each image was obtained through the average ratings given by the four observers.

Images for this section:

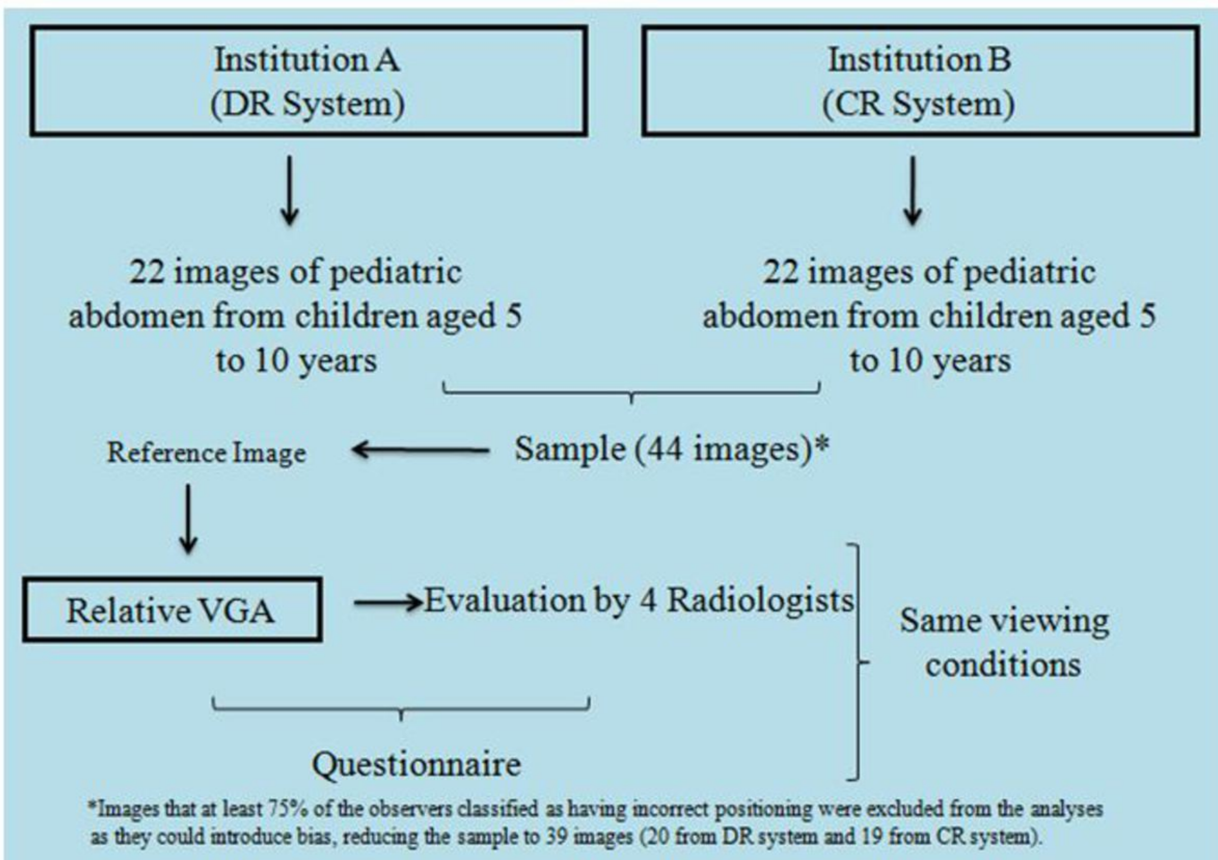

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Fig. 2

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Table 1 - Protocols used in institutions participating in the study

Table 1

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VGA Study

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Fig. 5

Results

The results of the patient positioning evaluation, collimation and centering point are presented on Figure 6.

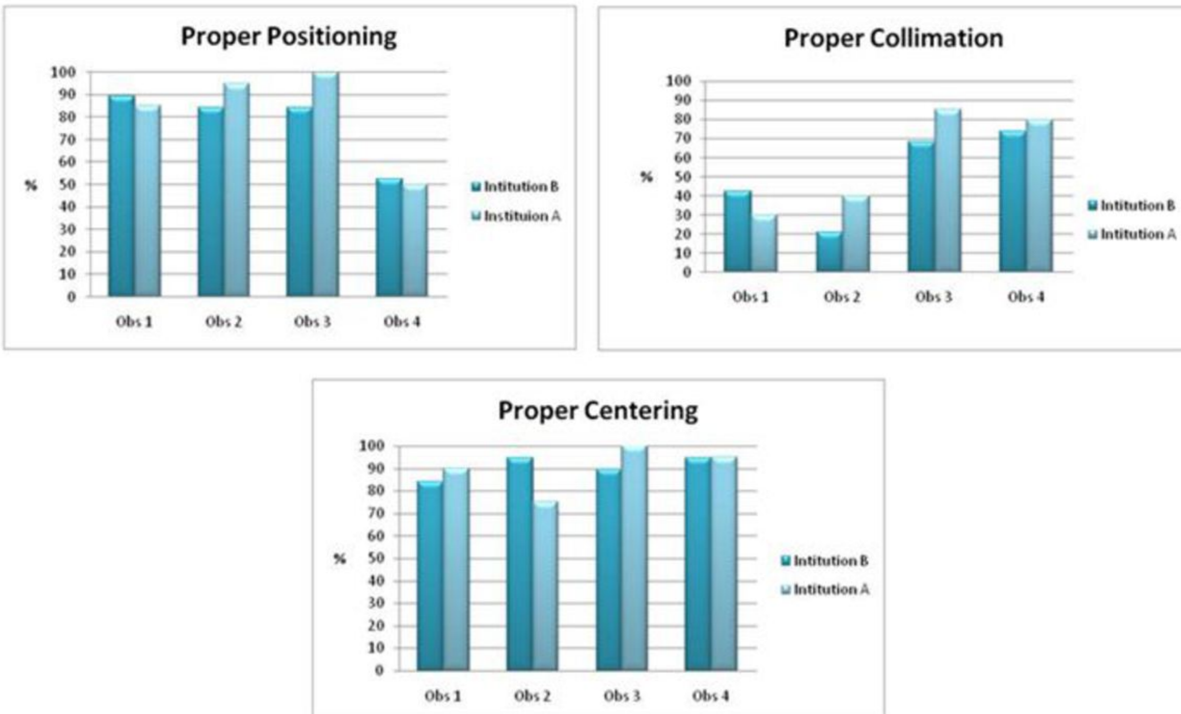

Figure 6 - Results from YES/NO analysis regarding positioning, collimation and centering

Fig. 6
References: - Aveiro/PT

The reliability study revealed an ICC value of 0,775, and that the 95% confidence interval varied between 0,633 and 0,872. As the ICC is relatively overhead, and the confidence interval has moderate amplitude, we can infer that the internal consistency degree is good. This result is statistically significant because the *p-value* obtained in the ICC (p<0,01) is less than 0,05 for a 95% confidence interval. Therefore we concluded that there is agreement amongst the observers. The exclusion of any of the observers did not produce an internal consistency improvement.

Based on the Levene´s test for #=0,05, and because the $p\text{-value}_{(Levene)}$= 0,369 is higher than #, we can conclude that the variances are similar. Consequently the *p-value* obtained in the t-Student test (p<0,01) is less than 0,05 which means that the mean scores obtained in the CR and DR systems are statistically different.

Independent Simples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Score total de cada imagem	Equal variances assumed	,827	,369	4,031	37	,000	,544053	,134957	,270603	,817502
	Equal variances not assumed			4,057	35,672	,000	,544053	,134092	,272014	,816091

Table 4 - Independent Samples Test

Table 4
References: - Aveiro/PT

The mean score found for the CR system (Mean = -0,217 and SD = 0,365) is less than the mean score found for the DR system (Mean = 0,327 and SD = 0,468), meaning that, according to the observers, the images obtained with the DR system presented a superior image quality comparing with those from the CR system.

Radiographic System	n	Mean	S.D.	Median	Minimum	Maximum
CR System	19	-0,217	0,365	-0,375	-0,667	0,542
DR System	20	0,327	0,468	0,354	-0,542	0,958

Table 5 - Statistical results

Table 5
References: - Aveiro/PT

Looking at Table 5 and the box-and-whisker plot (Figure 7) we can conclude that there are no outliers, the DR system median is higher than the one from the CR system and the variability on the CR system is lower than the one found on the results from the DR system. Both box-and-whisker plot presented symmetry.

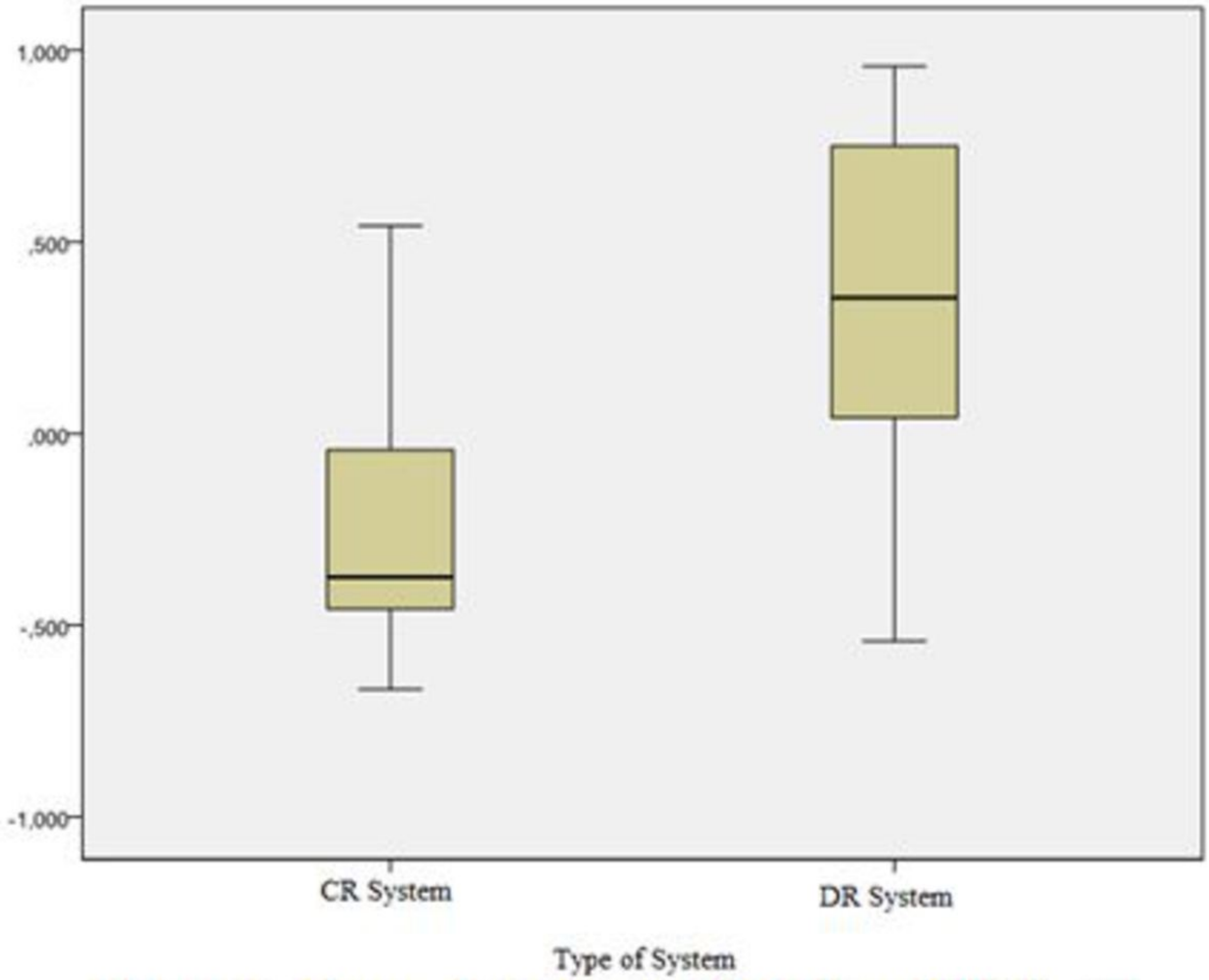

Figure 7 - Box-and-whisker plot for CR and DR Systems

Fig. 7
References: - Aveiro/PT

Concerning the estimated ESD values we found 517 μGy for the DR system and 740 μGy for the CR System; both within the reference doses for abdominal pediatric examinations for ages between 5 and 10 years old defined by ICRP (500-800 μGy) [6]. These results indicate that the DR system presents a dose value relatively lower than the one from the CR System. The difference between values is around 200 μGy.

Images for this section:

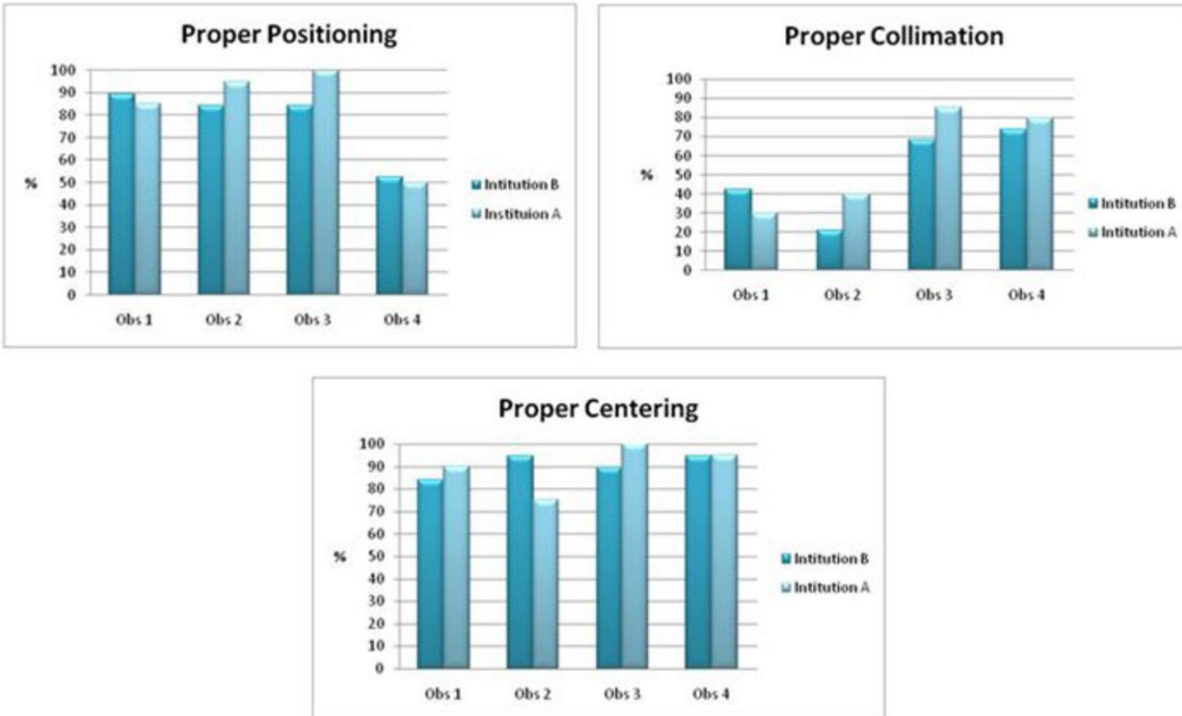

Figure 6 - Results from YES/NO analysis regarding positioning, collimation and centering

Fig. 6

Independent Simples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
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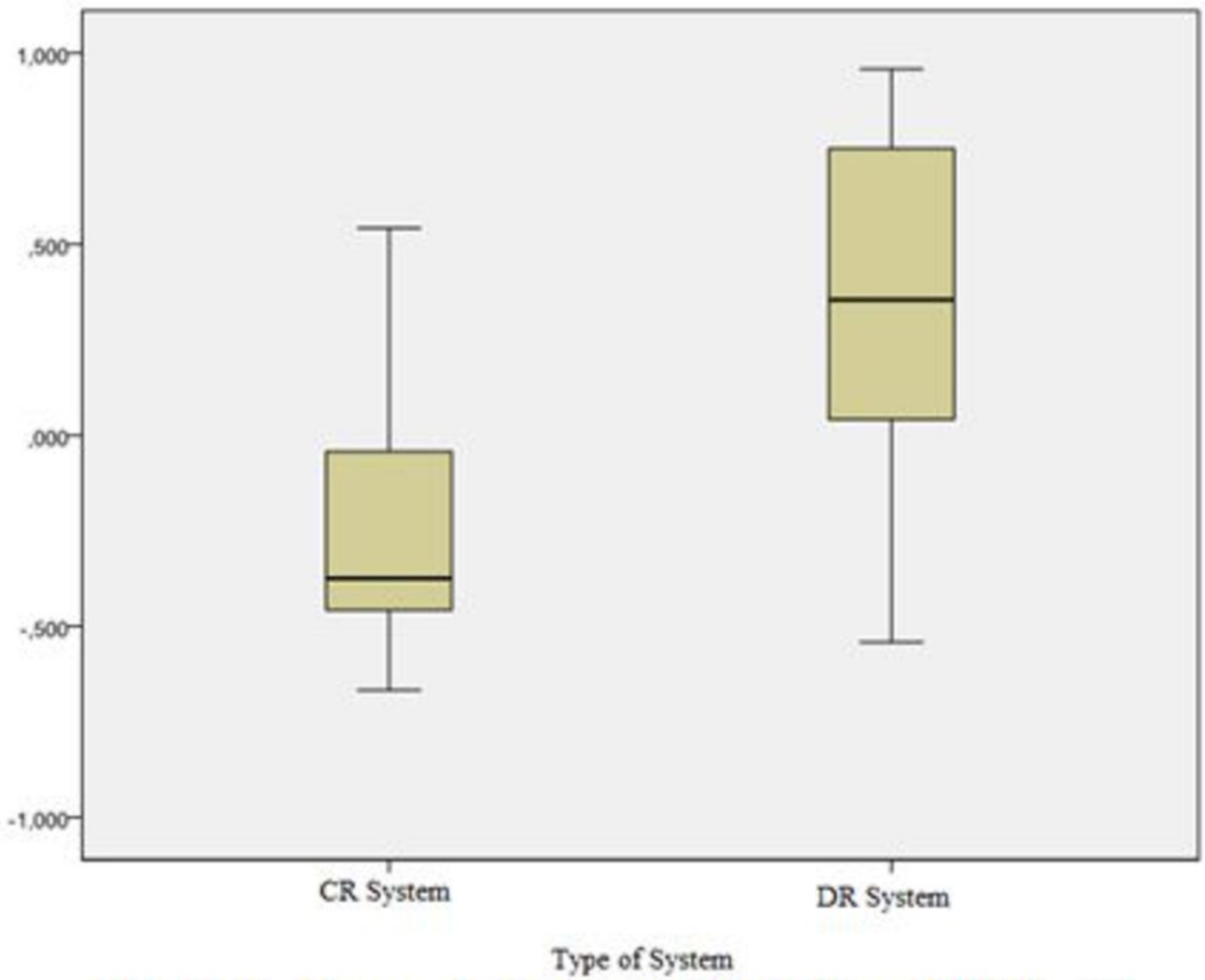

Figure 7 - Box-and-whisker plot for CR and DR Systems

Fig. 7

Conclusion

In the present study, the subjective image quality, as provided by VGA scores on pediatric abdominal images, was significantly higher when using the DR system compared to the one obtained using the CR system. Moreover, based on the calculated ESD results, we can suggest that DR systems allowed a 30% dose reduction when compared with CR systems. These results indicate, that patient dose reduction can be achieved by using DR system without loss of the required diagnostic image quality [11].This might be due to the higher quantum detection efficiency provided by DR systems and it is in line with the results reported for chest studies with a similar approach [12, 13].

It is important to notice that ESD results obtained by both systems are within the reference doses defined by the ICRP for patients aged between 5 to 10 years old, such as the patients participating in this study, although these reference values are defined for screen-film systems and not digital systems [6]. Dose reference levels for digital systems are not currently available preventing a more thorough comparison. Dose reduction can be attained if optimized protocols, devoted for digital systems, were implemented.

Although not directly related to the system where the images are acquired, general principles such as correct positioning, beam limitation and centering have a great impact on image quality and most importantly on patient dose. Unnecessary repetitions or poor image quality can be avoided if these rules are applied [4]. In this study, according to the observers, proper positioning and centering was generally achieved (80-100%) in both institutions. However, beam collimation was rated, at least by two observers, as inadequate in about 50% of the images. Beam collimation is relevant, mainly in pediatric patients due to dose concerns. Furthermore, if the field-size is too large an increment in scattering radiation leads to a decrease in contrast with a negative impact on image quality. Following best practices is of utmost importance to reduce patient doses and this matter should deserve great attention from the institutions and their professionals.

Although regulation on radiation protection is already incorporated in national legislative documents, in Portugal a real implementation of these recommendations in daily clinical practice is far from being achieved. Furthermore, typical distributions of exposure parameters in plain radiography are unknown and there are few studies about reduction/ optimization exposure doses, which become more relevant in pediatric patients [1].

The present study represents a small but important contribute to this topic since it compares image quality in CR and DR systems establishing a relationship with patient dose, in pediatric patients. Even with doses within acceptable limits, the potential for dose reduction was noted. Results should be analyzed and shared with the participating institutions to develop adequate imaging protocols. In the future, we recommend that other anatomical areas and direct measures of ESD are considered using a larger sample.

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